CHAPTER 4
MECHANICAL SYSTEMS

4-1. Mechanical design criteria

The intent of the LVD concept, described in paragraph 2-3, Limited Vulnerability Design Concept, is to create a facility that is self-sufficient and capable of surviving a single internal threat event. For mechanical systems, this requires a design that provides the ability to adapt in response to a detected flood, explosion, or CBR event within an area and thereby protects the remaining spaces for the duration of the mission. Paragraph 4-7b(1), Relative Pressurization, discusses these system reactions in detail. The designer should provide means by which service throughout the facility can meet mission RAM criteria. Some recommended methods are system redundancy, multiple utility services, and alternate fuel sources, as discussed in paragraph 4-3, System Reliability.

a. The ability to maintain functionality in the remaining spaces in spite of an event in a single zone is critical. Accordingly, the designer should design the mechanical systems serving those spaces in a manner that mitigates their inherent vulnerabilities to internal threat events. An added benefit of such design considerations is that many of the measures that reduce the vulnerability of facilities also provide enhanced protection against natural and accidental incidents. However, the designer should ensure that any measures taken to reduce the vulnerability of the facility to an internal attack do not inhibit normal operation. The measures must also be capable of immediate, seamless implementation and should follow a regular testing and maintenance schedule.

b. At a minimum, the designer should consider the following basic criteria to ensure self-sufficiency and reliability of mechanical systems in the design of C4ISR facilities.

(1) There should be at least two independent sources for external utilities.

(2) Mechanical systems at a minimum redundancy of N+2 should serve mission-critical zones (such as command centers).

(3) All external critical utilities (such as water or natural gas) should include an internal well, internal storage capacity, or alternate fuel that is sufficient for the established facility mission time. The water source should be sufficient for potable and makeup water uses.

4-2. Applicable codes and standards for mechanical systems

The following codes and standards govern the design of mechanical systems as part of the LVD concept:

a. TM 5-691, Utility Systems Design Requirements for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities

b. TM 5-810-1, Mechanical Design: Heating, Ventilating, and Air Conditioning

4-3. System reliability

The overall level of reliability required for the operation of a C4ISR facility is very high. To achieve this, the LVD concept supports the creation of self-supporting peripheral zones serving a central command center. These peripheral zones contain less critical functions, enabling the facility as a whole to accept the loss of a single peripheral zone to an internal event as long as service to the surviving zones remains intact. For this purpose, the LVD concept incorporates dedicated mechanical systems and utility connections for each zone. The functions of the command center are the most critical to the facility mission. Consequently, the designer should take extra measures to improve the reliability of systems serving it. In accordance with this requirement, the designer should consider the use of system redundancy and alternate fuels, specifically with regard to achieving the minimum required N+2 redundancy for the command center.

a. Redundancy is a proven concept used to increase system reliability, in the LVD concept, the peripheral zones house dedicated mechanical rooms. These rooms contain the main mechanical equipment and hydronic piping mains. They also provide the entry point for all external utilities serving the building. Building operation depends on having adequate backup to all critical systems in the event of a disruption in a single zone. Therefore, redundancy for both external utilities and HVAC systems is required.

(1) Under normal operation, C4ISR facility operation typically relies on public utility systems. These utilities include water, sewer, and natural gas. Given the reliability requirements for the facility, however, dependence on a single source for these utilities is not recommended. The designer should coordinate with other disciplines and local utility providers to ensure that the utilities brought to the site have at least two independent sources.

(a) Each zone should have dedicated taps off these utility mains, with appropriate contaminant sensors, backflow prevention (on water), and shutoff capabilities to protect the main lines. Paragraph 4-5, Automatic Isolation and Backfeed, discusses these devices in more detail.

(b) A dedicated sewer line and storm drain system should also support each zone. The sewer lines should not combine into a common line until outside the facility perimeter. Composting toilets or other means should be available in case sewer service is lost due to an event. Any storm drains serving the command center area should route through the peripheral zone systems. Overflow capability is typically required for a storm drain system design per code and should be adequate for system backup.

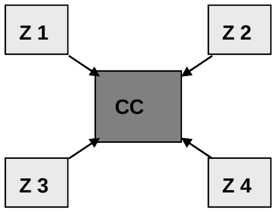
(2) Heating, ventilation, and air-conditioning should also utilize redundancy to increase system reliability. In addition to serving the associated zone, each peripheral mechanical system (wet and dry side) should share an equal portion of the command center load to meet the N+2 redundancy criteria. The designer should size each zone's mechanical systems so that if an event during maintenance were to result in the loss of two of the supporting peripheral zones, the remaining mechanical systems would be able to handle 100 percent of the command center load (see figure 4-1). If the number of peripheral zones exceeds five, to limit the system cross-connections, the designer should select only five of those zones (spread throughout the building) to serve the command center. Similarly, the computer air-conditioning units (CACs) located within the command center should support the load so that two units can be lost without affecting the command center.

b. The requirements for self-sufficiency dictate the provision of internal sources for utilities that are critical to facility operation. Some of these requirements are:

(1) In the case of water, each zone may have an internal well or storage tank. In the case of fuel for boilers and generators, liquid fuel (diesel) is likely to be the most practical to store internally, but compressed natural gas, propane, or other fuels may be considered.

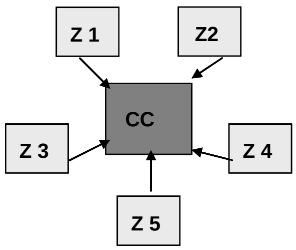
(2) Storage capacity should be based on the defined mission time for each specific facility and may require significant physical space. For example, to provide 3 days of storage for the example facility would require approximately 14,000 gallons of water and approximately 4,600 gallons of diesel fuel for

each of the four peripheral zones. This may dictate adding a below-grade level to the building dedicated to storage tanks.



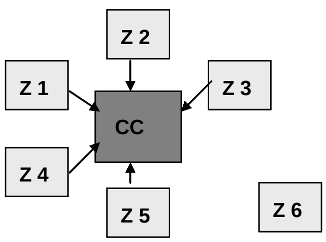
FOUR PERIPHERAL ZONES

ZONE CAPACITY (Contribution Equivalent to 2 Zones down)	NORMAL CONTRIBUTION TO COMMAND CENTER (CC)	ZONE CONTRIBUTION WITH ONE ZONE DOWN
Zone + 50% CC	25%	Zone + 33%CC



FIVE PERIPHERAL ZONES

ZONE CAPACITY (Contribution Equivalent to 2 Zones Down)	NORMAL CONTRIBUTION TO COMMAND CENTER (CC)	ZONE CONTRIBUTION WITH ONE ZONE DOWN
Zone + 33% CC	20%	Zone + 25%CC



SIX PERIPHERAL ZONES

ZONE CAPACITY (Contribution Equivalent to 2 Zones Down)	NORMAL CONTRIBUTION TO COMMAND CENTER (CC)	ZONE CONTRIBUTION WITH ONE ZONE DOWN
Zone + 33% CC	20%	Zone + 25%CC

Figure 4-1. Scaled peripheral zone support of the command center

4-4. Plumbing distribution system configuration

Each peripheral zone requires access to systems served by external utilities. One approach the designer may use involves pressurized loops around the building. Figure 4-2 illustrates this approach, showing the main lines for two external utilities (water and gas) routed in loops around the example facility, inside the secure perimeter. Two independent external sources (labeled W1, W2, G1, and G2 in the figure) serve each loop as discussed in paragraph 4-3a(1), External Utilities. These sources are provided with check valves to prevent backflow. The loops are also equipped with shutoff valves to isolate a portion of the loop should it be damaged. To meet the self-sufficiency criteria, a third source of water (labeled W3 in the figure) is required for each zone. This may be a well or a storage tank but, in either case, should be located within or beneath the zone. These sources should be of sufficient size to provide makeup water to the zone cooling tower (if the required storage tank size is prohibitively large, air-cooled heat rejection should be considered).

a. The designer may choose to provide storage capacity for natural gas as well, but the alternate liquid fuel option may be more feasible. In either case, fuel storage capacity should be provided in each zone. Taps off the main line provide dedicated service to each zone. These taps should have hydro-pneumatic tanks on the lines to replace losses due to leakage. The command center receives domestic water service from taps off the dedicated zone water lines. Design of the domestic hot water system is at the discretion of the designer and is not critical for mission operation.

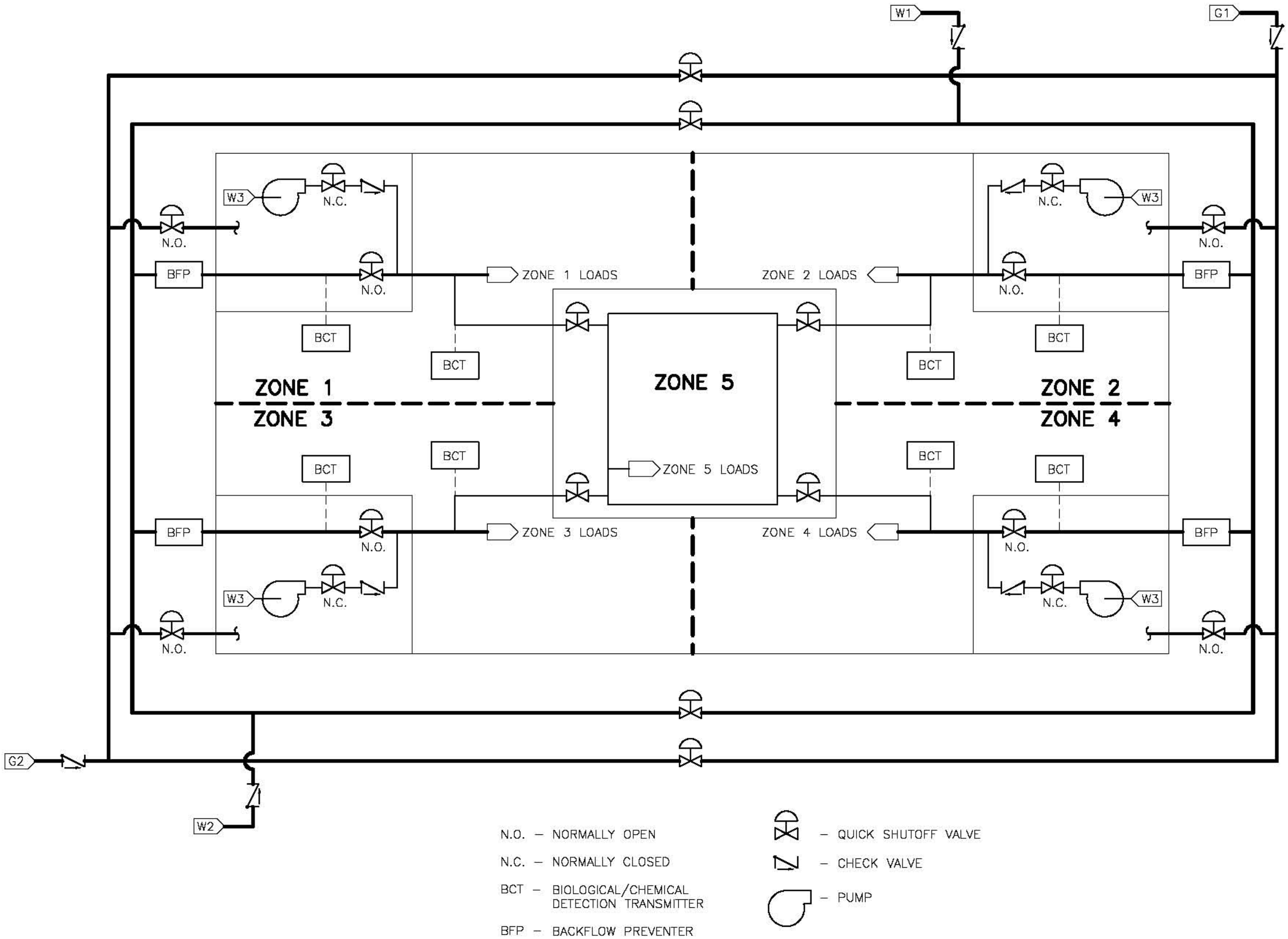


Figure 4-2. Zoned utility connections

b. Locating utility loops inside the secure perimeter should protect the local water and gas mains from potential threats; however, the designer should also consider protecting the building from sewer system tampering. The sewer lines and storm drains for each zone should preferably route to the exterior of the building rather than passing beneath another zone. Potential vulnerabilities in a sewer system include those of explosion and system backflow. In addition to zoning the vent and waste lines, the designer could address these vulnerabilities by including a couple of extra design precautions. Recommended precautions involve oversizing the system vents to reduce the effects of explosion and terminating the vents with goosenecks at the roof level to deter the introduction of foreign substances. Another precaution is to include backwater valves in the sewer lines to prevent CBR contamination of the building through sewer system backflow. Secured cleanouts for water and waste lines should be located inside the building. Vent lines internal to the building and exiting to the building roof are not defensible through mechanical means; protection of these is dependent on limitation of access to the roof.

4-5. Plumbing system – automatic isolation and backfeed

The designer can mitigate the vulnerability of plumbing systems to CBR contamination by employing the redundancy of sources and system segregation techniques discussed previously. The designer should also take additional measures by providing backflow protection, detection, and isolation devices, as follows:

a. Equip zone water lines with a control valve for isolation, coupled with contaminant detection upstream of the valve. Electrically actuated isolation valves, controlled from a central system, automatically close upon detection of a contaminant within the main utility stream. This measure prevents contaminants introduced at the utility level from contaminating everything downstream.

b. Provide additional shutoff and detection devices on the water lines between the peripheral zone and the command center to protect the water from zone-level contamination.

c. Include shutoff valves in the main loop to permit isolation and partial operation of the loop in the event that one side is damaged. These devices should close upon loss of pressure on one side of the loop.

d. Where appropriate, equip utilities with backflow prevention devices. These devices prevent contamination at the zone level from leeching back into the main supply line and rendering it unusable for other zones. Also provide backflow prevention (such as check valves) in the utility source lines to prevent loss of flow from the loop if pressure is lost in a source line.

4-6. Fire protection water and suppression systems

Fire protection water follows the same configuration as domestic water: it is looped beneath the building, with each zone tapped separately from the main line through the appropriate shutoff and backflow prevention. Due to the large volume required, fire protection water typically does not have an internal water tank as backup.

a. This is acceptable because the command center, housing the most critical facility functions, is provided with a clean-agent fire suppression system in lieu of a fire sprinkler system. External water tanks or surface water sources may be considered for backup of the regular fire protection system under special circumstances such as remotely located facilities.

b. The command center fire suppression system is a clean-agent delivery system designed to safeguard both the equipment and occupants within the command center. To minimize the impact on command center operations, the suppression system should be controlled in two stages. This facility is assumed to be staffed on a continuous basis; therefore, the first line of defense in the event of a fire should allow the staff the opportunity to address the fire with hand-held equipment. Thus, the first control stage for the system should be to alarm only. The second stage should activate the automatic clean-agent fire suppression system to extinguish the fire. The location of the clean-agent tanks and controls for this system should be within the command center secure zone.

4-7. Heating, ventilation, and air-conditioning systems

In addition to providing general space conditioning and occupant comfort, the goal of an HVAC system design generally is "…to achieve isolation of contaminated spaces and provision of safe egress paths or safe refuges for building occupants" (American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE] Journal, September 2004). C4ISR facilities are unique in that the continuance of the mission is more critical than the survival of building occupants in a zone affected by an event. Nevertheless, the LVD concept endeavors to safeguard personnel to the degree possible while still supporting the mission. The intent is to accomplish this purpose using available proven technologies or strategies, not specialized systems. Some potential strategies are pressurization, filtration, and isolation of systems.

a. Figures 4-3a and 4-3b illustrate the relationship of the zone HVAC systems to their associated zone and to the command center. Figure 4-3c conveys a more detailed schematic of the wet side at the mechanical room. All peripheral zones have similar configurations, as shown in figures 4-3a, b, and c. In this example, each of the four zones can support the zone load plus 50 percent of the command center load as discussed in paragraph 4-3a(2), Heating, Ventilation, and Air-Conditioning.

b. The rooftop makeup air-handling units (MAUs) provide filtered fresh air for the zone air-handling units (AHUs) and the command center. The AHU mixes the space return air with the fresh air to supply air to the zone. A gas-fired boiler (B) provides heating water that warms the air stream while a water-cooled chiller (CH), paired with a roof-mounted cooling tower (CT) and condenser water pump (CWP), provides the means for cooling. CACs provide cooling for the command center, rejecting heat to the chilled water system. Heating water and chilled water pumps (HWP and CHWP) circulate the water to serve the zone-level MAU, AHU, and terminal unit coils. They also feed a pressurized loop within the command center serving the CACs. Roof-mounted exhaust fans (EF) pull exhaust air from the spaces.

(1) Building pressurization may have little effect during a flood or explosion, but it can provide a level of containment and protection in a fire or CBR release event. To compensate effectively for a CBR event, the building pressurization system should have the ability to be dynamic. The HVAC design should positively pressurize the entire C4ISR facility relative to the outdoors. The "level of pressurization should be based on the pressures that need to be overcome, primarily those due to wind and stack effects, but also those induced by system operation. Therefore, each building's pressurization strategy should be designed based on the climate, the building height and the envelope leakage" (ASHRAE Journal, September 2004). A pressure gradient should also exist between zones, resulting in airflow from critical areas to support zones and then to the building exterior. Upon detection of a contaminant, a special controls routine should initiate the shutdown of all supply to and exhaust from the contaminated space. Surrounding zones should increase pressurization with respect to the affected area by adjusting their fan speed to prevent cross-contamination. These adjustments in the mechanical systems should keep the contaminant contained within the zone of origin.

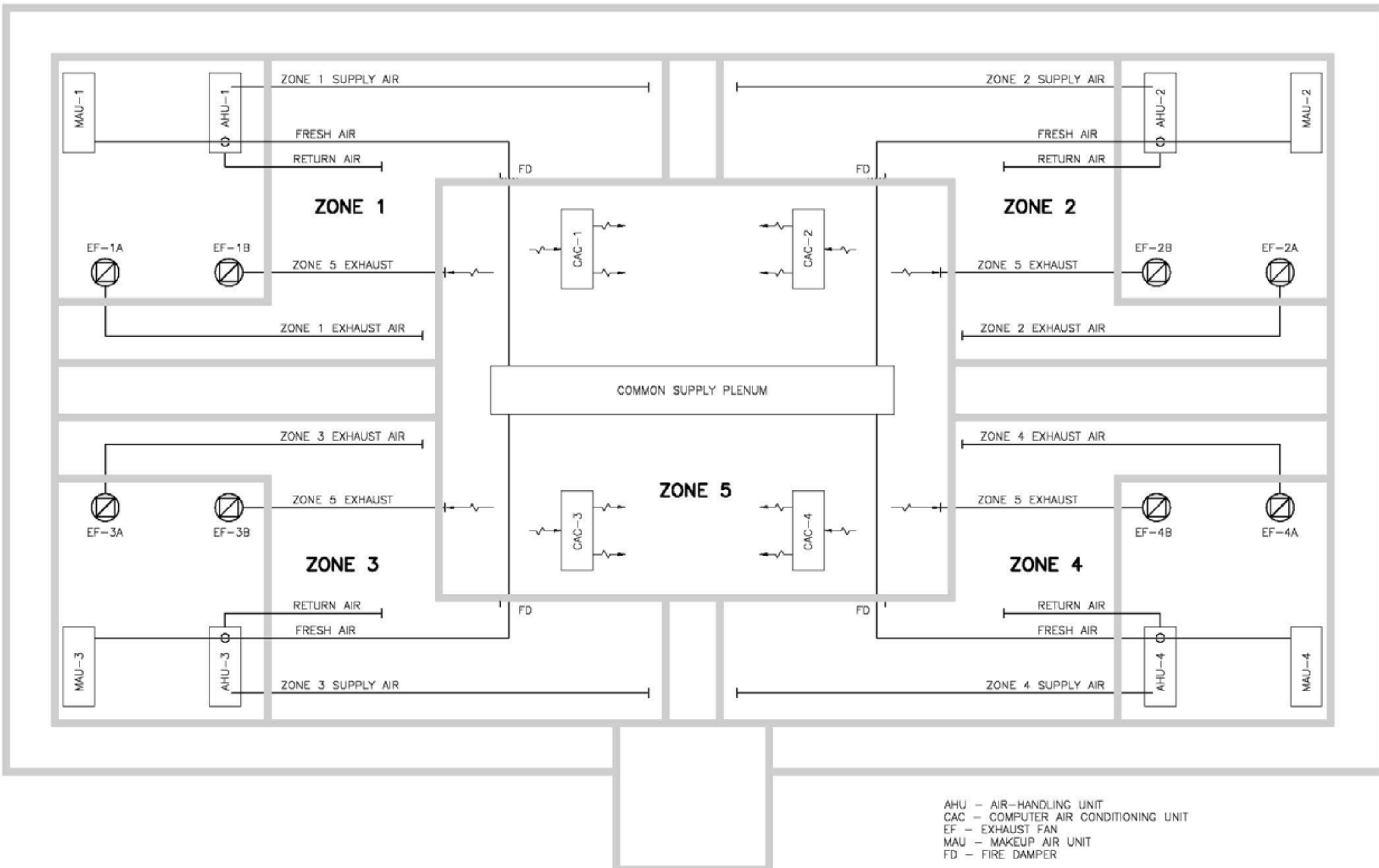


Figure 4-3a . Dry side schematic plan view of HVAC system

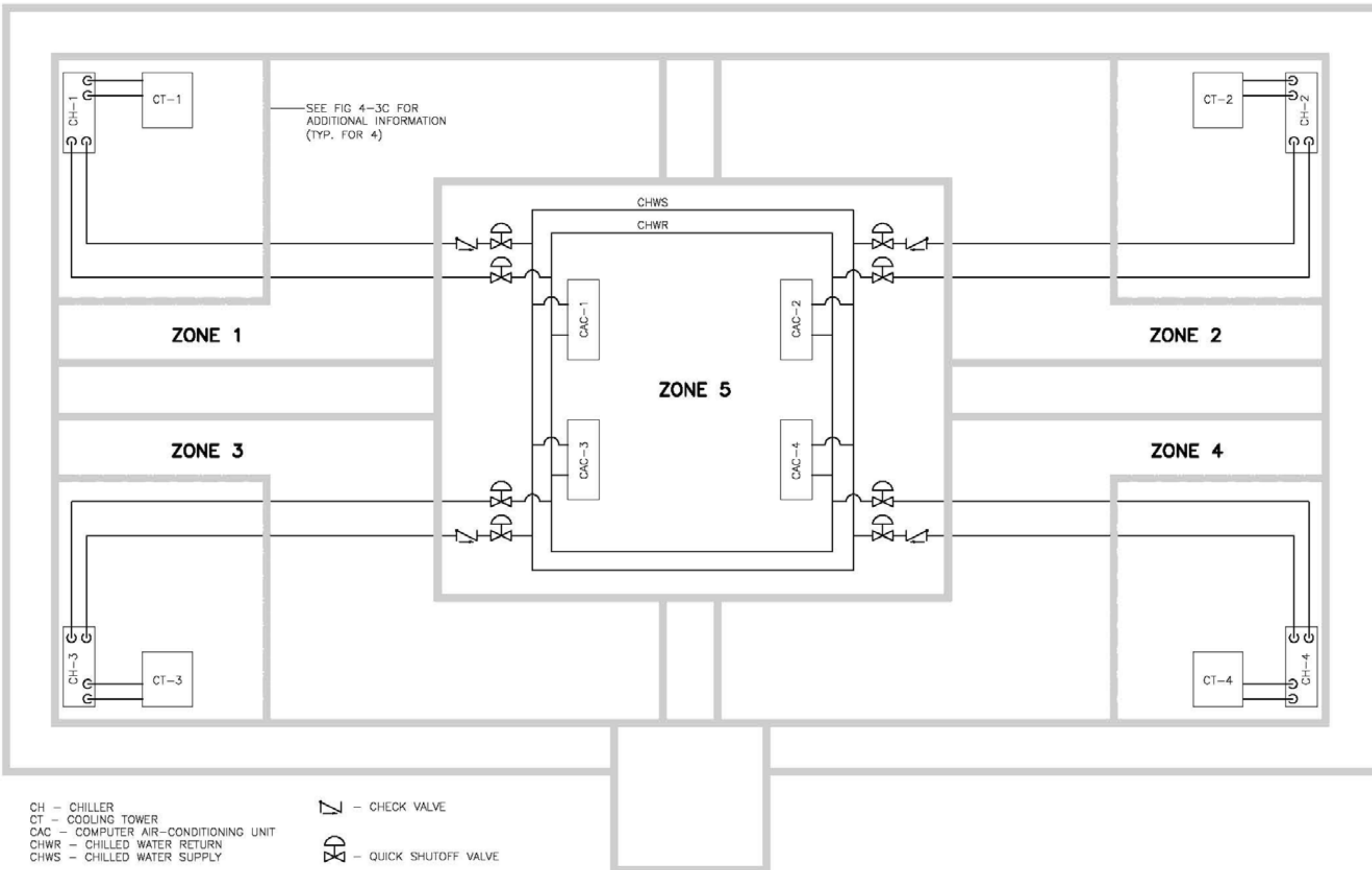


Figure 4-3b. Wet side schematic plan view of HVAC system

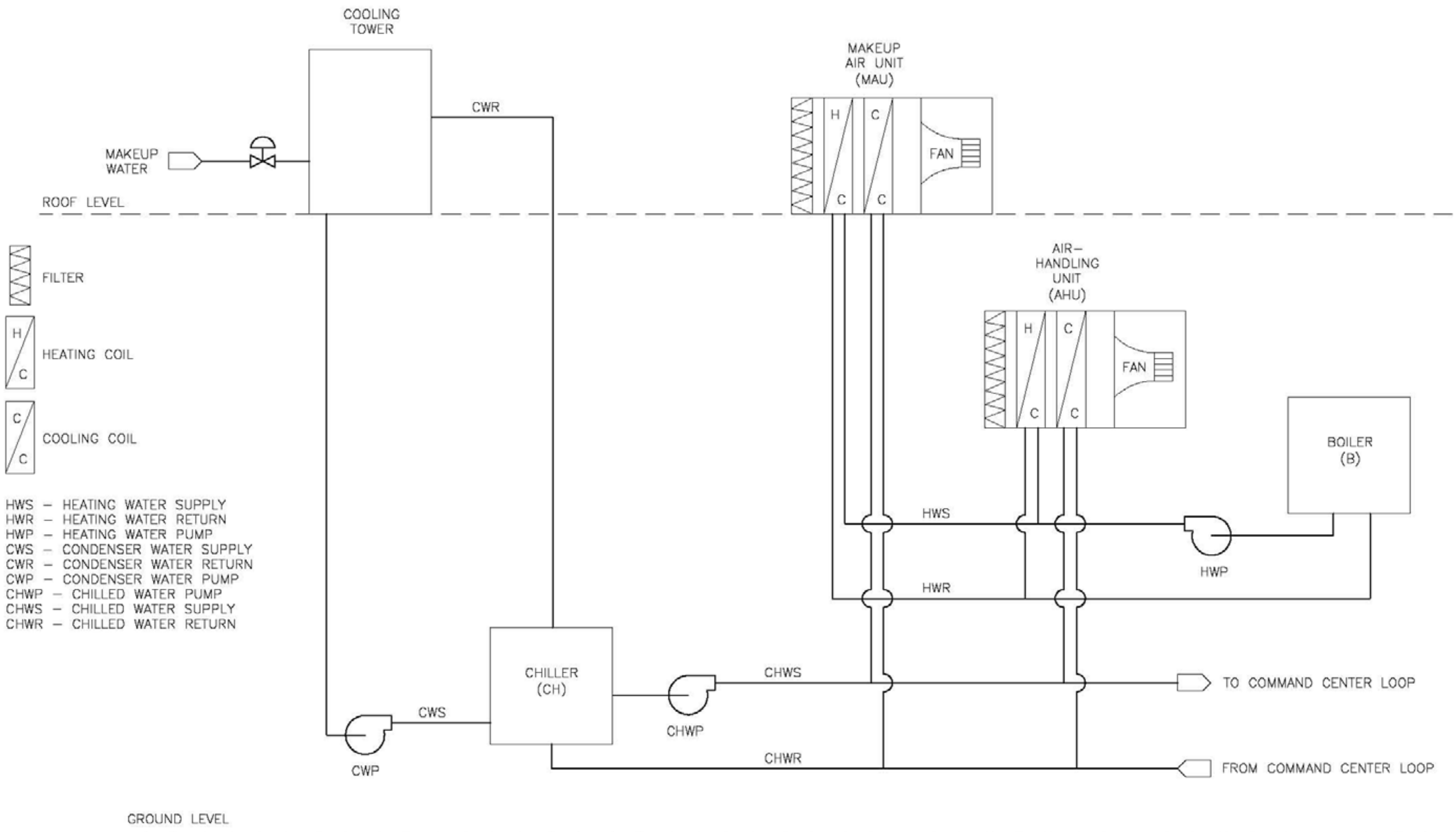


Figure 4-3c. Wet side schematic diagram of a typical mechanical room

(a) Though the mission is the primary concern, the mechanical system should also maximize the potential for egress from a contaminated space. Any event detected in a zone should initiate a response from the mechanical system. The designer should provide the perimeter corridors with air from the nearest peripheral zone system. Central corridors (those providing egress from the command center) and vestibules should be pressurized using conditioned air from the command center. These corridors should always be at higher pressure than the surrounding peripheral zones and perimeter corridors. This allows individuals evacuating a contaminated zone to exit through the common vestibule without risking cross-contamination to other zones. This higher level of pressurization also creates an added layer of zone separation.

(b) Figure 4-4 shows the relative pressurization of the example facility under normal operating conditions. The building is positive to the outdoors, preventing infiltration from an external CBR event. Within the building, the command center, the most critical zone, is positive to the peripheral zones, where pressurization levels are equal relative to one another. The building pressurization would adjust as shown in figure 4-5 upon detection of an event in Zone 2. Shutdown of supply and exhaust should permit the contaminated space (in this case, Zone 2) to slowly move toward equilibrium with the outside through exfiltration. The MAUs and associated AHUs serving adjacent zones would ramp up to provide additional pressurization to their associated zones to prevent contamination. Occupants of Zone 2 could then safely exit the contaminated zone through the adjacent perimeter corridors.

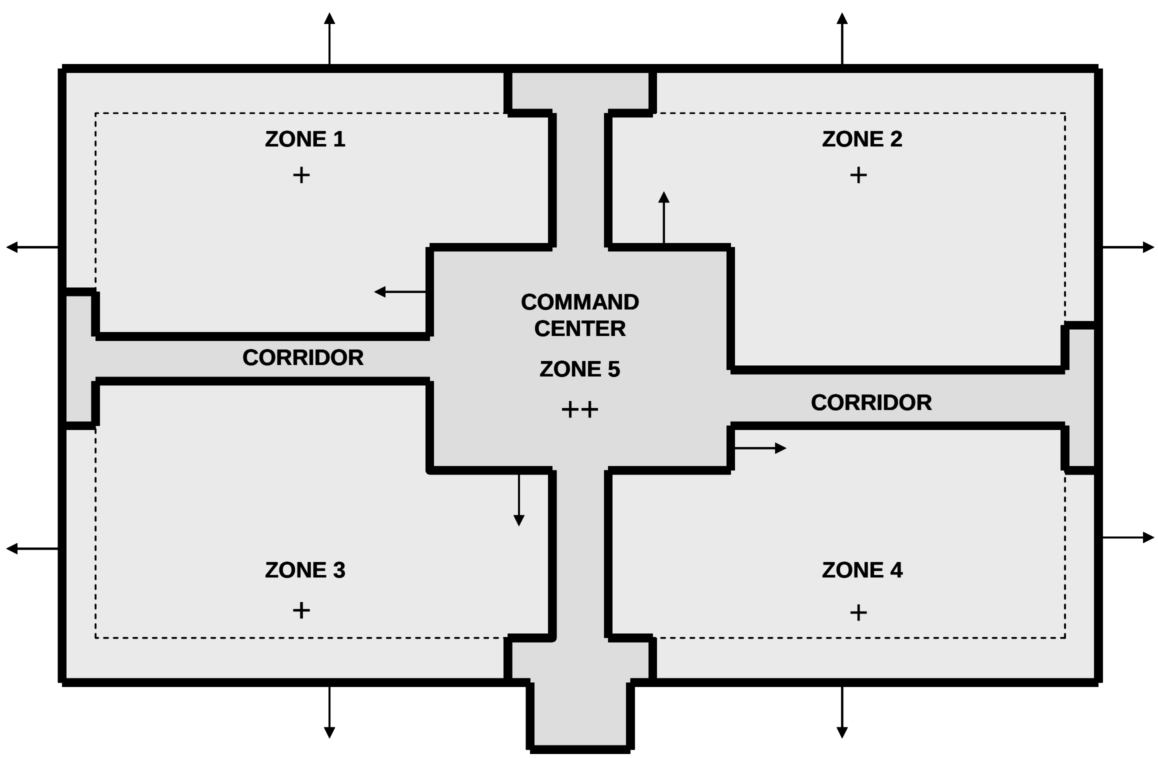


Figure 4-4. Normal pressurization

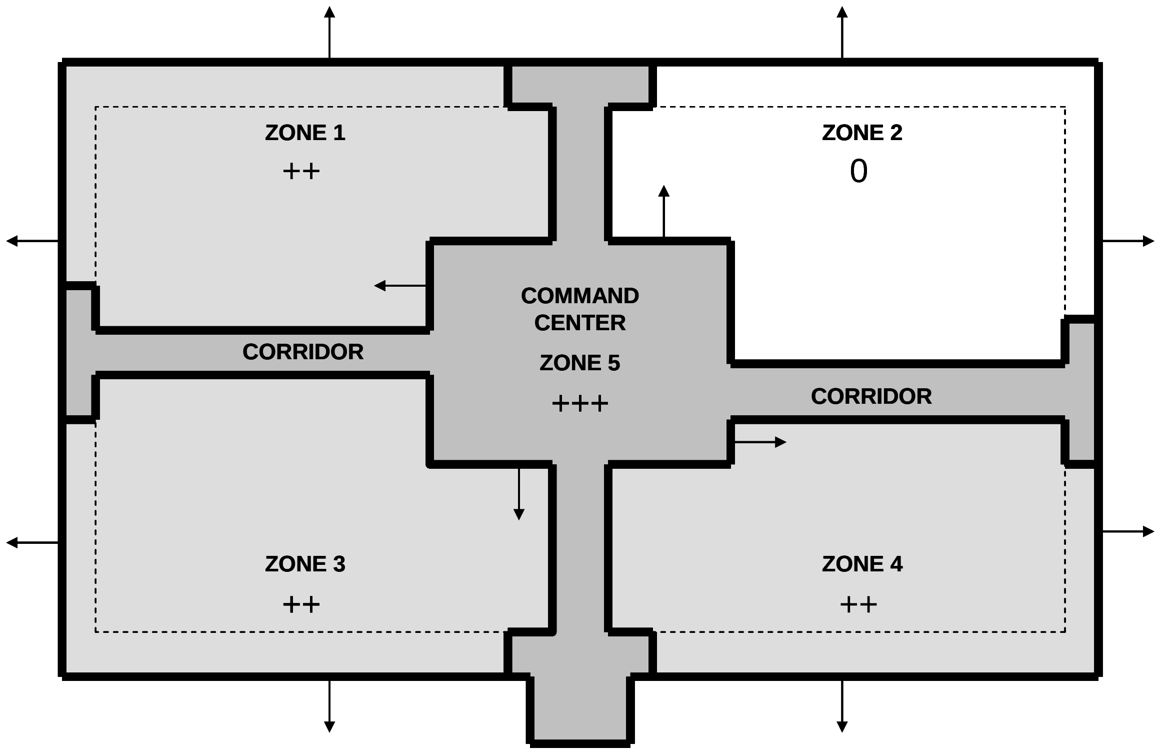


Figure 4-5. Emergency pressurization

(2) The design of mechanical systems for the LVD concept should rely on standard equipment and a segregation strategy rather than specialized systems. With this strategy, the loss of some peripheral zones is acceptable as long as the command center remains operable. Thus, the AHUs serving the zones need only to follow standard commercial design practice for filtration. However, the design of the MAUs should include filtration in accordance with standard guidelines for CBR protection. Use of CBR filtration on the MAUs not only provides an additional level of protection for building occupants, but also expedites cleanup efforts of a contaminated zone. PPE such as gas masks, suits, and gloves should also be available to occupants in the case of a CBR event. The designer may also choose to supplement the filters with ultraviolet light (type C) emitters located within the MAUs to act as a germicide.

(3) Chilled and heating water systems serve the MAU, AHU, CAC, and terminal unit coils in a facility. Provided that they undergo proper maintenance, these systems are less vulnerable to a CBR attack than other systems. However, chilled water is an especially critical system due to the cooling requirements for equipment in the command center. An explosion or similar event is more likely to affect this particular system. Hydronic systems should have quick shutoff devices on the supply and return side of the water loops to prevent loss of water from the command center loop in the event a zone is lost. The supply side should also have a check valve.

(a) These devices should be located within the command center zone. Once these devices shut off a zone, the unaffected zones will continue to support the command center loop. Hydro-pneumatic tanks should be provided in the chilled water lines (just prior to the shutoff valves) in other zones to replace chilled water leak loads. TM-5-691 contains additional discussion of hydronic system vulnerabilities and equipment configuration.

(b) The size and quantity of CACs required to cool the command center depends on the types and amount of electronic equipment, the number of occupants, and the arrangement of the space. For illustration purposes, four units are shown serving the command center, but the actual number should be determined from load calculations and the N+2 redundancy requirement.

(4) Isolation and control devices used in the control of mechanical systems also should be readily available technologies, not specialized systems. For instance, the controls developed to modulate air-handling systems for building pressurization in a CBR event should be similar to the industry standard strategies and devices for smoke control. Automatic, quick-shutoff, piston- or electrically actuated solenoid control valves for utilities are available in sizes as large as 2 inches in diameter. For larger water pipes up to 8 inches in diameter, electrically actuated, spring-return butterfly valves are available. These devices should operate in less than 10 seconds with fail-safe positioning, typically fail closed. Actuators on time-critical dampers (which must open or close quickly, such as emergency generator exhaust dampers) should be a spring-return type with a safety function.